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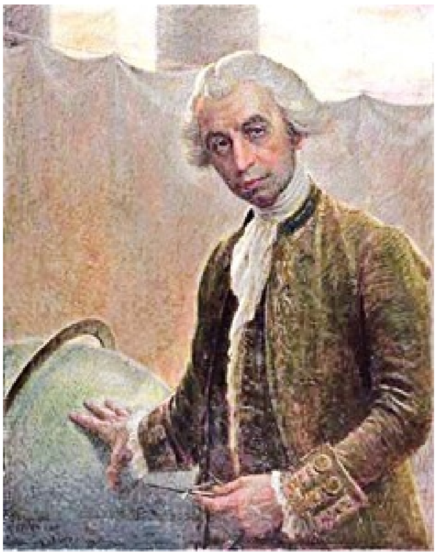

RUDJER BOSKOVIC
(1711 - 1787)

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Belgrade, 13-14 October 2022
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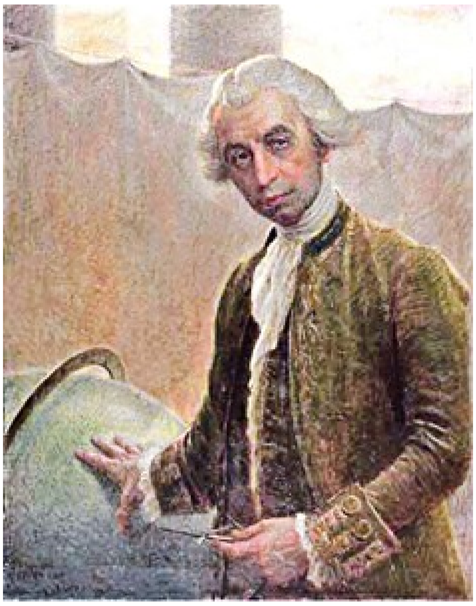

Rudjer Boskovic
(1711 – 1787)
He has left an indelible imprint in mathematics, astronomy, physics, optics, geodesy, architecture, archeology, pedagogy, philosophy, literature and diplomacy.

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FLIGHT PLAN PREPARATION FOR POINT CLOUD DATA COLLECTION UTILIZING THE LASER SCANNER ALS80HP

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Abstract: *This article describes the production of a flight plan to acquire point cloud data with a Leica ALS80 laser scanner to produce a high-resolution digital terrain model (DTM) as part of the IPA2014 project. When planning the flight, it is vital to examine the project tasks, the aircraft's technical prerequisites, and the laser scanner's characteristics, all of which influence the completion of the study. The initial part of the IPA2014 project, which intends to develop flood risk maps, entails creating a flight plan to scan the area of interest.*

Consequently, a summary of the project's structure, technical circumstances, and implementation requirements is provided through the planning of the flight plan. The objective, which is reflected in the effective flight planning and meteorological events, has been fully attained, indicating the successful preparatory research that preceded the planning and execution of the flight using the available aircraft and laser scanner Leica ALS80HP.

Keywords: *LiDAR, point cloud collection, remote sensing, MissionPro, DTM*

1. INTRODUCTION

In the past ten years, laser scanning has become an increasingly popular technique for collecting geospatial data, particularly the data necessary to generate a digital terrain model and other derivatives that provide a three-dimensional view of space. In conjunction with other geospatial data and research results derived from remote sensing techniques, a geospatial image is created that best portrays a terrain's geographic and topographical aspects. Collecting such data by laser scanning from airplane platforms involves careful planning that considers the sensor's features and the aircraft's performance. When planning a flight, it is essential to know the characteristics of the terrain that will be flown over, the project task, the desired outcome, and the final product resulting from the entire project. In the case of this paper, this meant the creation of vulnerability and flood risk maps through hydraulic modeling. This whole procedure represents a significant challenge for those who plan to implement such a task, not only in a professional sense but also involves additional research to satisfy all needs. The procedure was carried out without difficulty and simultaneously respecting the economy and productivity.

Part of the research was conducted prior to the actual acquisition of the equipment, i.e., the laser sensor, to evaluate the correctness of the permitted equipment in conjunction with the current equipment and, most importantly, the available aircraft.

The flight and laser scanning must be conducted in specified weather circumstances to avoid obtaining or collecting data that cannot be used appropriately and is valueless. Ideal weather conditions do not last long enough, so time and meteorological conditions contribute to the complexity. Satisfying all conditions established during the formulation of the flight plan for laser scanning data collecting is mandatory. This article will propose a flight planning solution utilizing a Leica ALS80HP laser scanner for the IPA2014 project to produce LiDAR point cloud, DTM, flood vulnerability and risk maps.

2. MATERIALS AND METHODS

Laser terrain scanning is a modern technique for collecting spatial data in the form of coordinates of points in space. In terms of recording type, laser recording might be either terrestrial or aero-photogrammetric. In both instances, data is collected that can be utilized to create digital two-dimensional drawings or three-dimensional models, whether a digital terrain model or a model of a distinct object. The most significant benefit of this approach is its precision and rapidity. Laser surveying of the ground can be conducted using an aerial platform, such as a helicopter, an airplane, or an unmanned aerial vehicle. The value of geographical data and its applications continues to rise. This is particularly true for building 3D city models, numerous engineering projects, gathering DTM data for orthophoto production, and developing large- and medium-scale geodetic base maps [1].

LiDAR is synonymous with laser technology for recording topography. The name LiDAR is derived from the phrase "Light Detection and Ranging," which describes a remote sensing method used to examine the surface of the Earth. With this technique, distances are measured using light or laser pulses, where, in conjunction with data from the platform's system and orientation, precise three-dimensional data about forms on the Earth's surface and their features are generated, and a digital terrain model (DTM) is created [2].

The fundamental components of the LiDAR system consist of a) a laser scanning unit, b) GPS receivers on the platform and the ground station, c) an inertial navigation system unit with an inertial measurement unit (IMU), and d) a data storage and processing unit [2].

In the name of the laser scanner used for the IPA2014 project (Leica ALS80HP), the ALS80 designation represents an airborne laser scanner, i.e., a laser scanner designed for imaging from an aerial platform, whereas the HP designation denotes a general-purpose model for imaging at heights up to 3,500 meters above the ground [2].

2.1. Flight plan

With digital sensors, there are three fundamental forms of aerial photogrammetric surveying: 1) single line surveying, 2) corridor surveying, and 3) interest area or block surveying. Therefore, flight plans are established to execute aerial photography in which the flight lines have a specific correlation.

1) A unique line is only defined by its starting and stopping points. This is a practical method for recording a profile. Figure 1 depicts a flight plan for capturing a mountain profile using a line sensor.

Figure 1. Illustration of the single-line recording

2) A corridor is a defined polyline that is formed of lines in varying forms with a specific width zone along a predetermined buffer zone. This mode is appropriate for surveying specific corridor directions and transportation routes (Figure 2).

3) The Area Of Interest (AOI) is defined by polygons that are required to be covered by parallel flight lines. It is utilized for zonal recording and to produce DTM. For precautionary purposes, this zone is extended during the software computation.

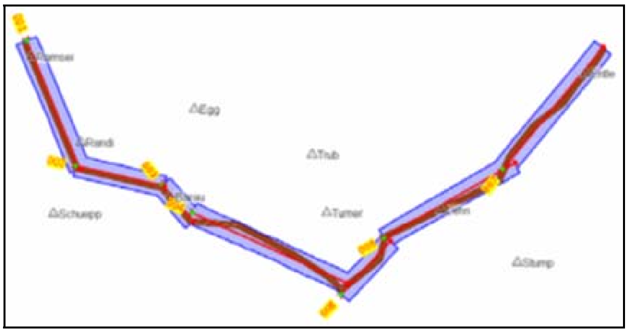

Figure 2. Illustration of a corridor recording

Due to the development requirements of flood risk maps, this form is utilized for the IPA2014 project (Figure 3).

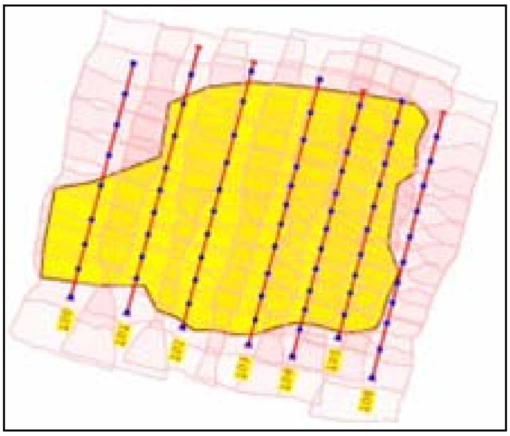

Figure 3. Illustration of an AOI recording

2.2. LiDAR recording requirements defined by the IPA2014 project

The IPA2014 project is an initiative of the European Union (EU) and the Republic of Serbia for the remediation of consequences that occurred after catastrophic floods that struck the western part of Serbia due to heavy rainfall in the third week of May 2014 and to prevent future floods [3].

The EU Directive on flood risk assessment and management, in conjunction with directive 2007/60/EC [4], reduces flood risk management activities to three procedures: preliminary flood risk assessment, risk assessment in which vulnerability maps are created, and flood risk maps and flood risk management plans [3]. The project's goal is to create flood vulnerability and risk maps. It is predicated on creating a DTM surrounding the defined flood zones with a horizontal accuracy of up to 0.5 meters and a vertical accuracy of up to 0.3 meters [5]. We refer to sensors mounted on aerial platforms when focusing on aerial photogrammetry and LiDAR recording technology. These platforms can be airplanes, helicopters, satellites, drones, or other aircraft. As it is planned to conduct LiDAR surveys using the Piper Seneca V aircraft as part of the IPA2014 project, the explanation of the flight planning concept will continue on such an example [2].

The following requirements are defined for LiDAR scanning of approximately 9,427 km^2 by the IPA2014 project:

a) The point density must be more than or equal to 5 points per square meter for flat regions and greater than or equal to 8 points per square meter for mountainous areas. To maintain homogeneity of gathered data, the ratio between the average distance of points in the direction of the flight line (dx, Along-track mean spacing) and the average distance of points perpendicular to the direction of flight (dy, Cross-track mean spacing) must not exceed 2 to 3;

b) Perform laser scanning with a planned 30 percent transverse overlap of the scanning lines. The variation between the actual and planned transverse overlap of the scanning lines shall not exceed one-third of the transverse overlap;

c) Utilize the GNSS station's "AGROS" network maintained by Republic Geodetic Authority for LiDAR scanning. At each scanning point, the distance between the aircraft and the permanent (or virtual) GNSS station must not exceed 30 kilometers (including the aircraft's turn). Utilize at least two permanent (or virtual) GNSS stations for LiDAR scanning;

d) To prevent an unfavorable satellite constellation, the aircraft's inclination during the turn to scan the following row must not exceed 25 degrees;

e) When collecting data, the "8" flying method must be applied before and after the LiDAR scanning [5].

2.3. Technical requirements for flight plan preparation

The DTM base is a crucial component for flight planning. It is always recommended to utilize the most precise DTM of the mapped region, but if one is unavailable, the global DTM - Shuttle Radar Topography Mission (SRTM) - may be used instead. SRTM is substantially less accurate than national and local digital terrain models, although it may still be used for flight planning.

The flight planning criteria having the most significant impact have been identified from aerial photogrammetry surveys conducted for Military Geographical Institute (MGI) projects. These include point density, Delta Scan, Range Gate, and the aircraft's minimum safe speed.

Point cloud density is the number of laser reflections measured per square meter. In LiDAR-based research, the outcomes are determined mainly by the density of points [6].

As illustrated in Figure 4, the point cloud density relies on the number of return signals per scan line (Sweep) and the number of scan lines that may be acquired in a given moment (Run) [7].

A correctly defined Delta Scan parameter will prevent the occurrence of duplicate points and the creation of the commonly named false point cloud density. To prevent the mentioned phenomena, the value of this parameter should be close to 0.5.

Factors that affect this parameter and must be corresponding are the flight speed, the angular range of the recording, the flight altitude, and the number of pulses of the laser sensor per second.

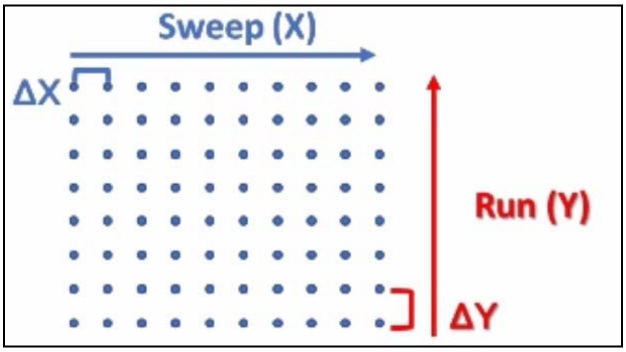

Figure 4. Factors affecting point cloud density [7]

The Range Gate explains the altitude during flight and the altitude change allowed during flight, so the highest peaks of the AOI are captured. The most common mistake when planning a flight is neglecting the height of objects. For example, if the lowest altitude at the AOI is 0 meters above sea level, the highest altitude is 150 meters above sea level, and the relative height of the building is 100 meters, this would mean that if the terrain recording is planned in the range from 0 to 150 meters above sea level, then there would be no data for a building located on the ground at the altitude of 100 meters because its top would be at an altitude of 200 meters (Figure 5).

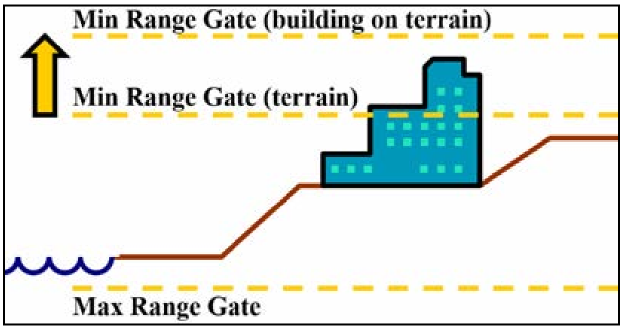

Figure 5. The problem of neglecting building height during flight planning

During laser scanning, it is essential to maintain the slowest feasible airplane speed. Light aircraft that fit this condition is thus used for this purpose. However, while discussing the aircraft's lowest speed, it must be kept in mind that this speed must be safe and sustainable for operation. Specifically, this value for the Piper SENECA V aircraft held by the MGI is 90 knots (1 knot = 1.85 km/h), whereas the recording speed ranges from 90 to 145 knots. Lower speeds are avoided as a safety precaution because they may result in engine cooling.

On the contrary, higher speeds would not have a beneficial impact on the density of points. This characteristic is highly affected by wind speed. For instance, the aircraft is flown at around 150 knots to achieve the desired speed if the wind in the opposite direction of the aircraft's movement is projected to be 40 knots. Due to the engine cooling, such an approach would be impossible in the reverse direction of the aircraft. It states that the lowest safe speed of the airplane is a relative element that depends on the variables.

2.4. Flight plan production

In the MissionPro software environment, the flight plan is developed by defining the parameters based on automated calculations, which generate the project as a flight plan for a specific set of parameters. In order for the aircraft navigation system and the operational controller to read the project, it is exported in a format with the extension *.fpd2. Furthermore, MissionPro includes the possibility of the flight review, which addresses the issue of whether the actual flight followed the schedule, considering costs and quality. This software's application areas are all related and dependent on each other to operate.

MissionPro is a planning tool that allows the scheduling of scanning jobs from all aerial platforms' sensors, including LiDAR, line, and frame sensors. It is completely interoperable with all other Leica services, tools, and equipment. This program combines all earlier products of the same type within the company. Two- and three-dimensional spatial assistance is provided by MissionPro for the display of flight planning concepts.

The initial step in using the LiDAR system is to design the flight plan in this program. Figure 6 depicts how the LiDAR system and the software provided for the Leica company's models are used.

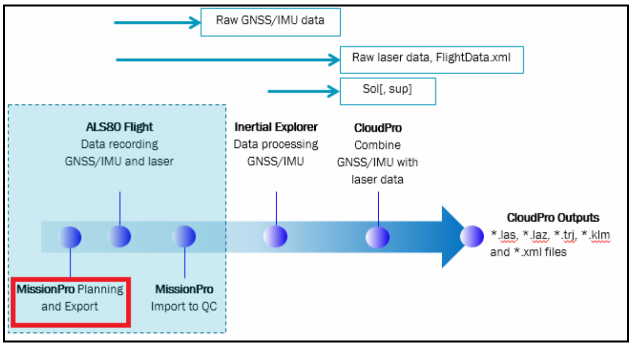

Figure 6. LiDAR system workflow

Both single-sensor and multi-sensor recording planning are targeted uses for the program. Multi-sensor imaging is typical for LiDAR recording, which requires simultaneous imaging with a digital aerial photogrammetry camera in addition to a laser sensor. In contrast, if recording from both sensors simultaneously is not feasible, each sensor must record the data separately within 15 days. This is the IPA2014 project requirement for data collection, so recording with an aerial photogrammetry camera and flight planning are performed separately.

The project requirement specifies that the transverse overlap along the flight lines must be recorded at a rate of 30%. However, the excess overlap, or the safety factor (minimum percentage of overlap under recording settings), is also established for precautionary purposes. In other words, depending on the circumstances during the actual flight, the flap will change and sometimes be less than the predetermined one. There could be issues with future data processing if this decrease is substantial, so the transverse overlap is not wide enough. As a result, a minimal overlap is defined that must be met and whose value will not interfere with further data processing.

While recording, the level of autonomy in adjusting the aircraft's flying altitude is determined by altitude parameters. Making as many favorable working environments is crucial. This also implies that the flight should be planned in line with the pilot's abilities and talents. Piloting is made simpler by avoiding rigorous maintenance of the plane's altitude.

The point density is defined as 5 per square meter for plain areas and 8 for mountainous areas, and within the flight plan preparation, it can be defined as the mean desired average point density and the worst-case average point density. The first value is entered as the density of points, which will be the average value of the density of points per square meter on the entire AOI, while the second value defines the worst possible density acceptable during recording and under the requirements of the project.

3. RESULTS

The division of the recording area carries out flight implementation and topography recording into polygonal "strips." A flight line in the center of each strip may be drawn to represent each flight plan graphically. The order of recording is determined by the flight lines, with the aircraft turning after each recorded line to record the following line in the opposite direction. Transversely, the recorded region on two adjacent flight lines overlaps by 30 percent following the angular range of sensor recording since it is required to preserve the integrity of the recording and the unity of the recorded information. The flight plan also specifies the manner of turning to the following flight line, the aircraft's turning angle, and the system startup procedure for the beginning and end of the recording. As stated, for the project's goals, the tilt during the turn for scanning the next row must not exceed 25 degrees to prevent an undesirable satellite constellation [2].

The "8" procedures are developed as integral components during the flight plan preparation. Method "8" is a required pre- and post-LiDAR scan procedure initialization, i.e., begins and stops operation of the IMU subsystem of the laser scanner during imaging based on the aircraft's typical figure-eight turn.

Additionally, the flight plan is constructed so that the distance between the aircraft and the permanent (or virtual) GNSS station at each scanning point (including the aircraft's turn) does not exceed 30 kilometers. As assistance for accurate positioning, these stations of the Active Geodetic Reference Base of Serbia ("AGROS") were constructed within the territory of the Republic of Serbia. It comprises 30 permanent GNSS stations from which continuous GNSS observations are produced, located at an average distance of around 70 kilometers and mostly mounted on local cadaster structures.

The scanner manufacturer recommends that the distance between first turns and permanent stations should not exceed 20 kilometers (Figure 7). The image depicts the draft of the flight plan and the maximum distance of 50 kilometers between the final point of the AOI and the station, which is 30 kilometers in the project task.

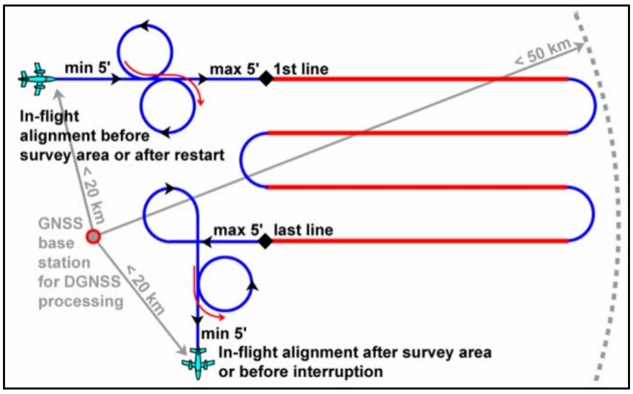

Figure 7. The draft of the flight plan concerning the position of the permanent stations

The Kolubara river basin's region is given as a LiDAR point cloud recording example. A large number of tributaries in its basin and the meanderings of the Kolubara River have impacted the decision to perform a segmentation recording. This requires recording the Kolubara River in seven sections, so its tributaries were recorded independently. The division of the recording territory is depicted in Figure 8 by flight lines for each territorial unit. Considering the various angles of each territorial unit's flight routes, the image illustrates the complexity of planning the recording of the entire region [2].

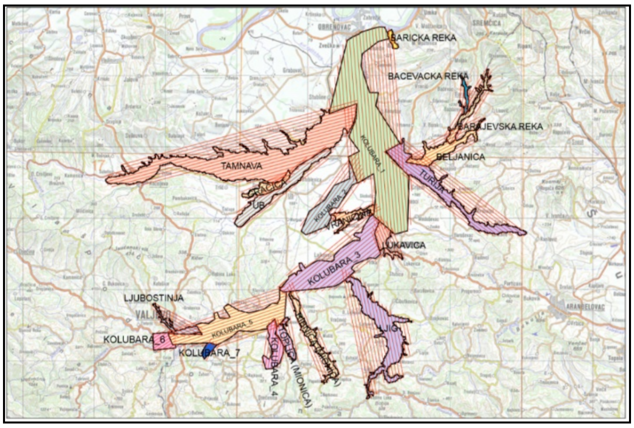

Figure 8. Kolubara River zones and flight lines

4. CONCLUSION

The article describes the complete process of the LiDAR survey flight plan for the area of interest, which is one of the phases of data collecting and processing for creating a flood risk map. The primary objective of this research was achieved, signifying that the flight preparation planning was carried out successfully and realized, facilitating data processing and the completion of subsequent phases of the project. It has been demonstrated that it is feasible to develop a flight plan that meets all the project's criteria as well as the technical capabilities of the aircraft (Piper SENECA V) and the laser sensor (Leica ALS80).

Part of the study was conducted prior to the actual acquisition of the equipment, i.e., the laser sensor, to assess the appropriateness of the equipment selection in conjunction with the current equipment and, most importantly, the available aircraft.

In general, LiDAR data collecting costs are less than aerial photo data collection, and processing times are shorter.

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